1st Advisory Board Workshop

Sodium-ion cells development

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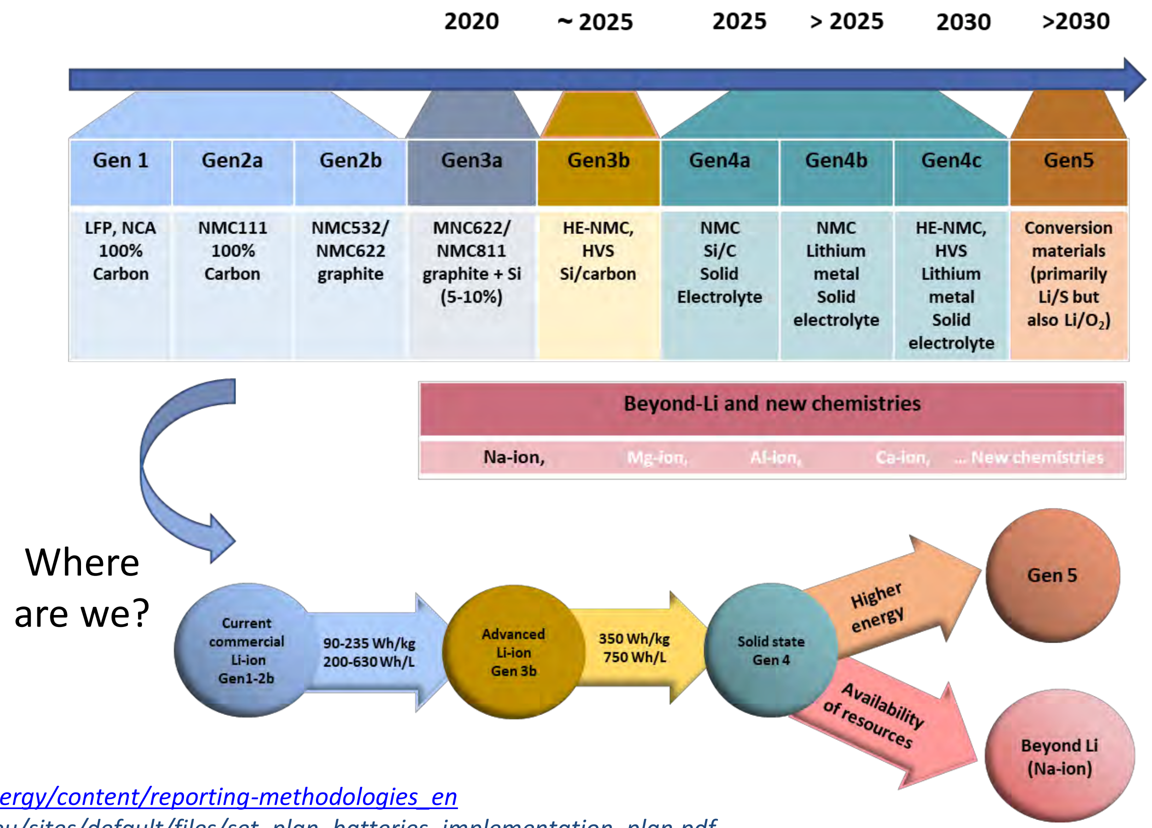
Next generation secondary batteries

The continuously growing demand for LIBs calls for improved cell technologies able to satisfy different energy requirement

The Strategic Energy Technology Plan (SET Plan) and cell generation classification:



There is plenty of room for innovative cell technologies: energy density is only one of the KPIs. Market diversification and different application requirements accelerate the research toward alternative chemistries:

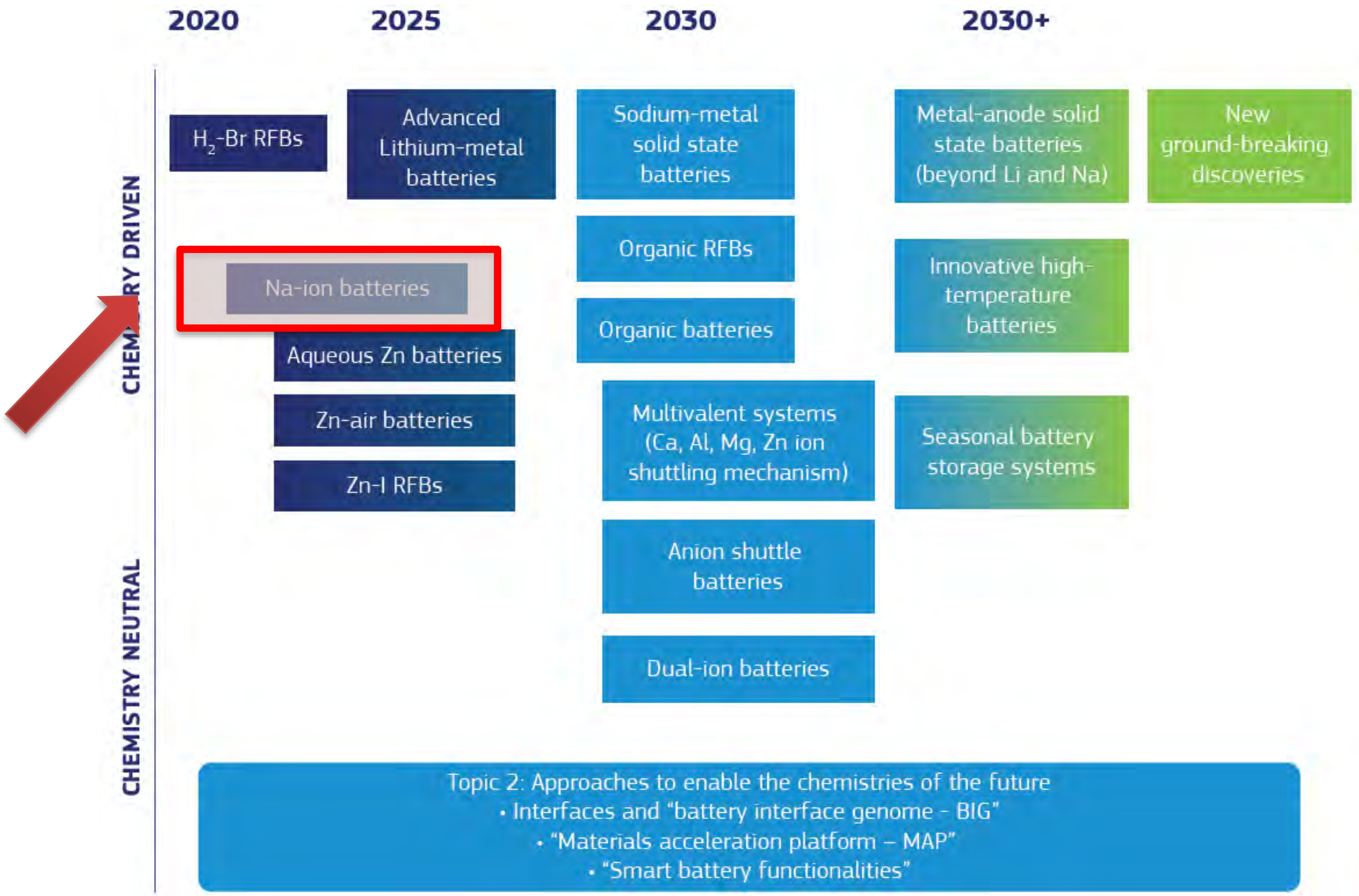
- Safety
- Cost
- Sustainability
- Dependency on raw critical materials
- Manufacturability

https://ec.europa.eu/energy/content/reporting-methodologies_en
https://setis.ec.europa.eu/sites/default/files/set_plan_batteries_implementation_plan.pdf
JRC-EU Competitiveness in Advanced Li Ion Batteries for E-Mobility and Stationary Storage Applications – Opportunities and Actions, 2017.

SIMBA
SODIUM-ION AND SODIUM METAL BATTERIES

Next generation secondary batteries: SIBs

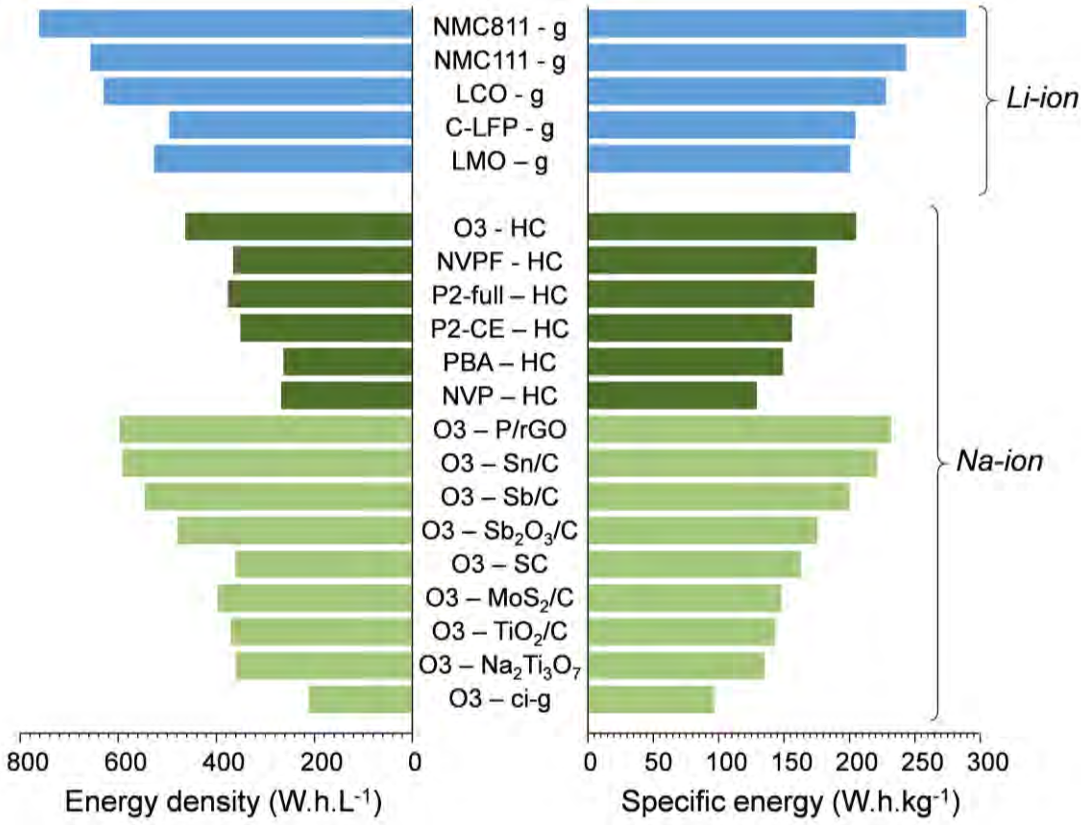
BATTERIES EUROPE
EUROPEAN TECHNOLOGY
AND INNOVATION PLATFORM

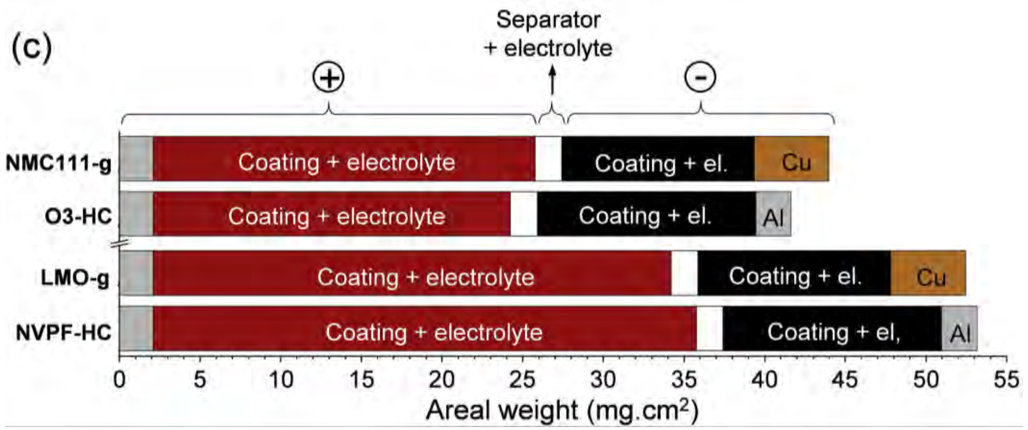


https://energy.ec.europa.eu/publications-new/roadmap-new-and-emerging-technologies_en

Comparing Li and Na-ion cells

Extrapolating full-cell performance metrics from academic literature reporting half-cell performance





(c) Weight of the various cell components, per cm^2, for a selection of Li-ion and Na-ion cells, calculated for an areal capacity of 3 mA h cm^{-2}

I. Hasa et al. Journal of Power Sources 482 (2021) 228872

Next generation secondary batteries: SIBs

SODIUM-ION AND SODIUM METAL BATTERIES

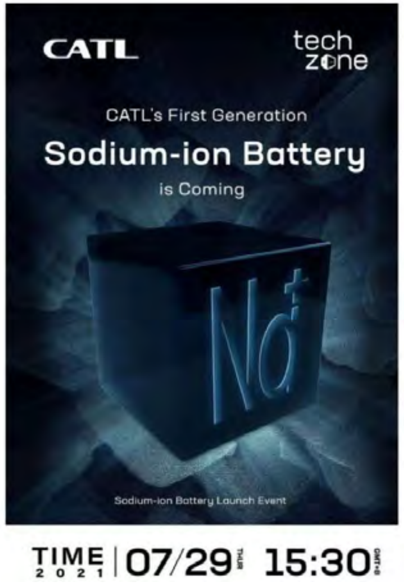
SIBs manufacturer: the game changers

Cell Level:
160 Wh/Kg Faradion (UK)
160Wh/Kg CATL (China)
120 Wh/Kg HiNa (China)
90 Wh/Kg TIAMAT (France)

http://www.tiamat-energy.com/

faradion

https://faradion.co.uk/
https://faradion.co.uk/reliance-new-energy-solar-to-acquire-faradion-limited/



https://www.catl.com/en/news/665.html

https://natron.energy/

中科海钠
HiNa BATTERY

https://www.hinabattery.com/en/

SIBs Applications

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Stationary Energy Storage

Na-ion batteries

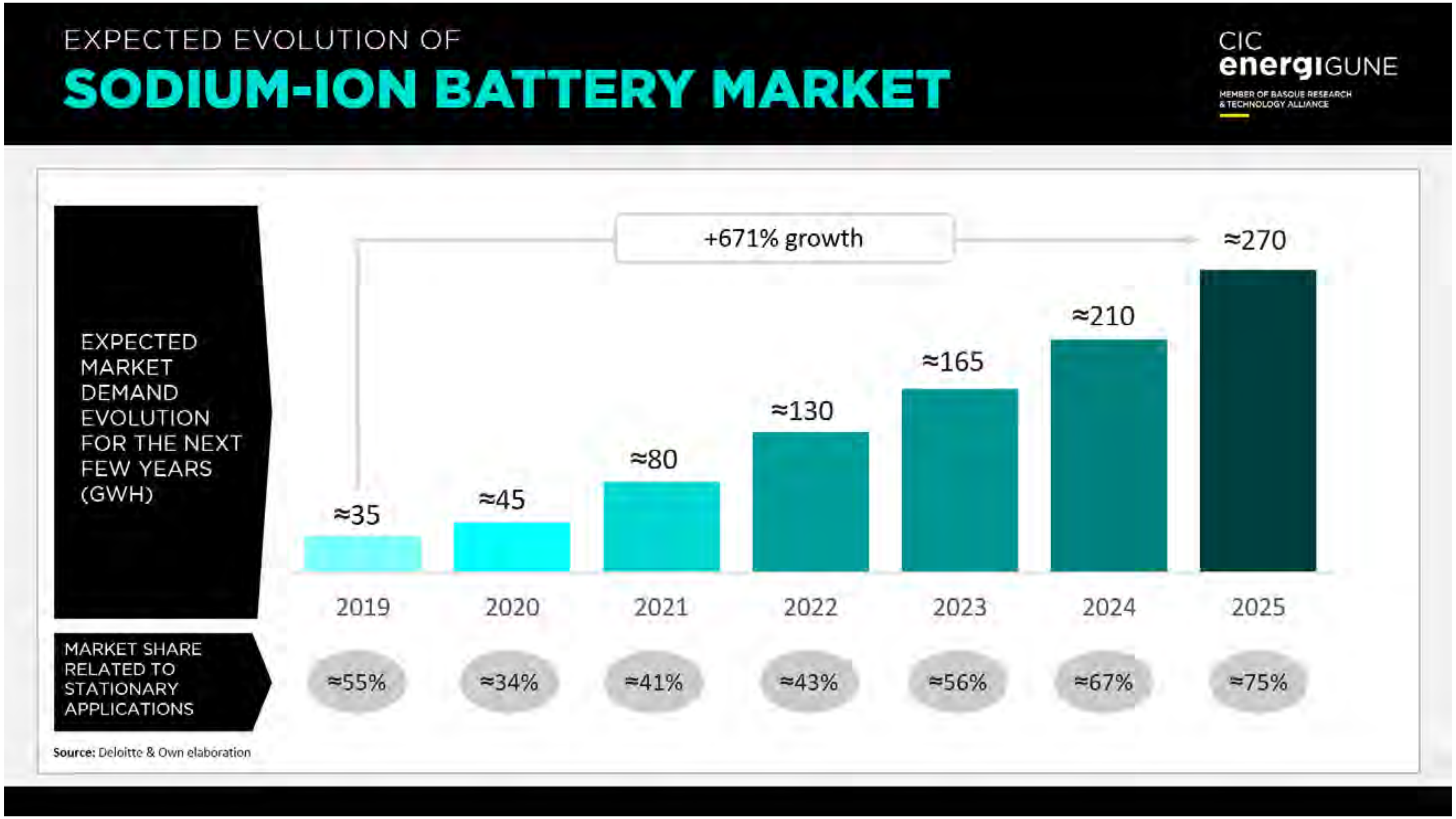
Na-ion batteries are ideal for stationary storage applications over a wide temperature range, thanks to their high energy density — both by mass and volume — combined with safety and cost advantages

Applications can include:

- Residential and industrial storage
- Back-up power supplies for telecoms
- Back-up power supplies or storage in remote applications and locations, including offshore

https://faradion.co.uk/applications/stationary-energy-storage/

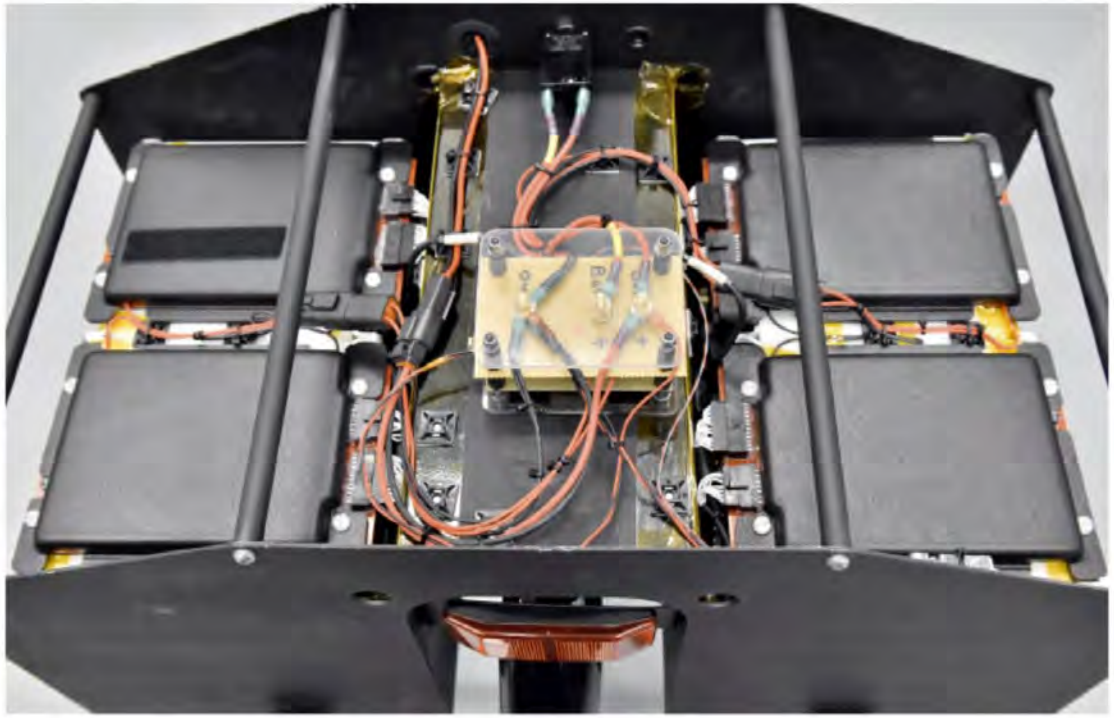
SIBs Applications



https://cicenergigune.com/en/blog/sodium-battery-perfect-sustainable-complement-lithium-batteries

SIBs Applications

Transport Applications



Sodium-ion cells

Our sodium-ion cells are an excellent drop-in replacement for lead-acid batteries for low cost electric transport – in LSEVs, e-scooters or as batteries for e-rickshaws and e-bikes – offering much greater range and carrying capacity for a similar price.

They also have potential for the S-L-I (starter-lighting-ignition) 12V battery or the 48V battery in a MHEV (mild hybrid electric vehicle). This is because Na-ion has higher energy density than lead acid batteries, as well as improved performance over a wide temperature range.

https://faradion.co.uk/applications/stationary-energy-storage/

Toward commercial SIBs

SODIUM-ION AND SODIUM METAL BATTERIES

The Scale-up and Commercialization of SIBs using Layered oxide cathodes

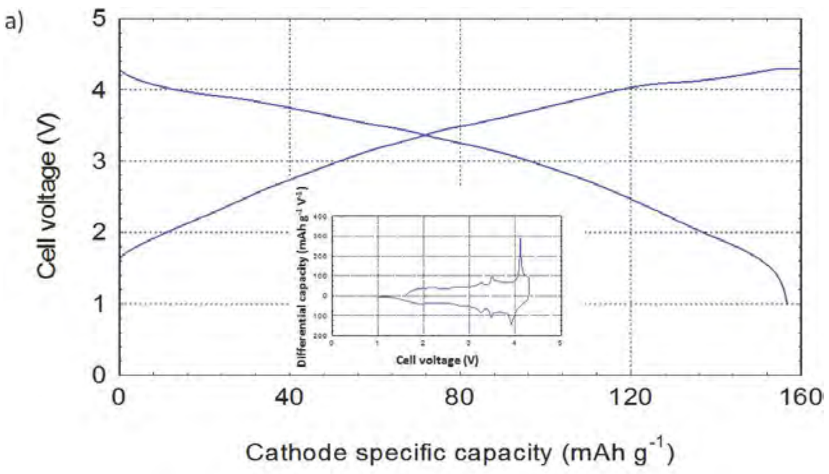
中科海钠 HiNa BATTERY

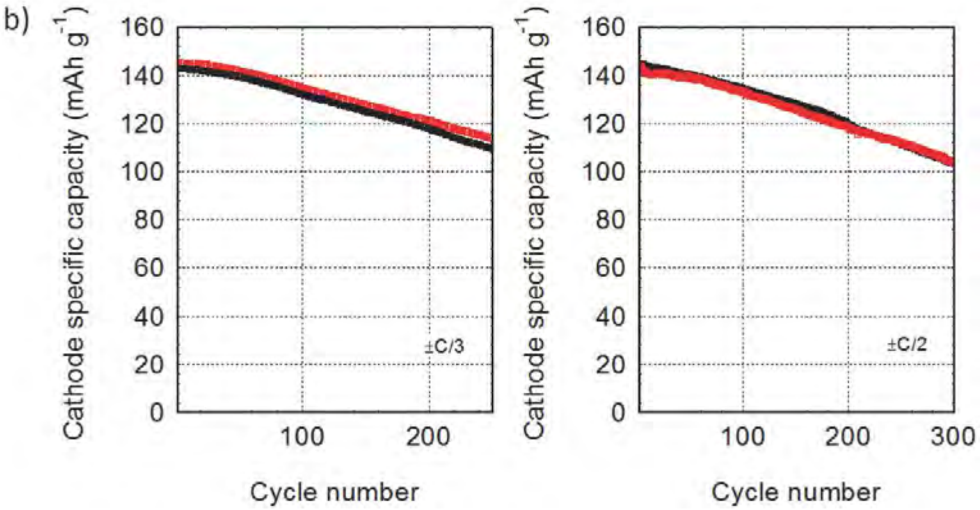
faradion

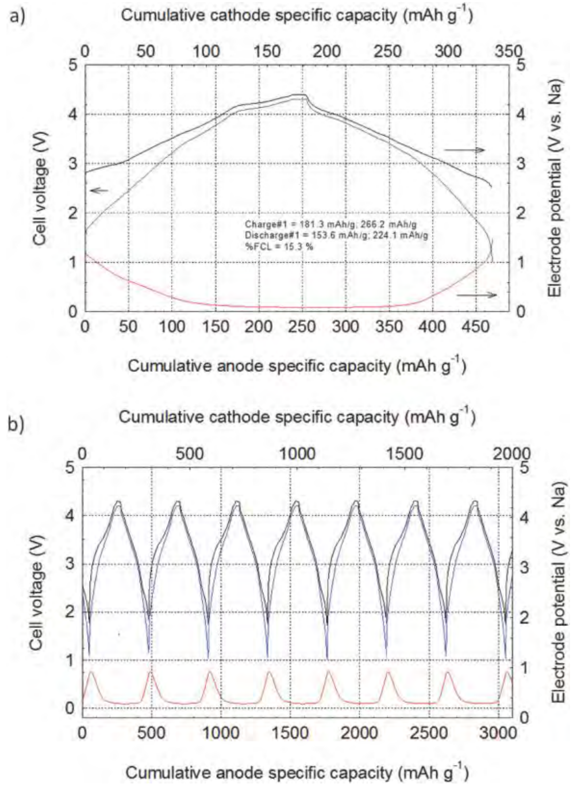
Demonstrations in prototype cells:
HiNa (China) using $Na_xCu_{1-y-z}Fe_yMn_zO_2$ as the positive electrode active material
Faradion (UK) using O3 or P2–O3 mixed phases of $Na_xNi_{1-x-y-z}Mg_xMn_yTi_zO_2$

a) Second cycle voltage profile and corresponding differential capacity profile; b) The cells were cycled at ±C/3 and ±C/2 at 30 °C. The cells were cycled between voltage limits of 1.0 and 4.3 V at 30 °C.

Faradion Na-ion cell.

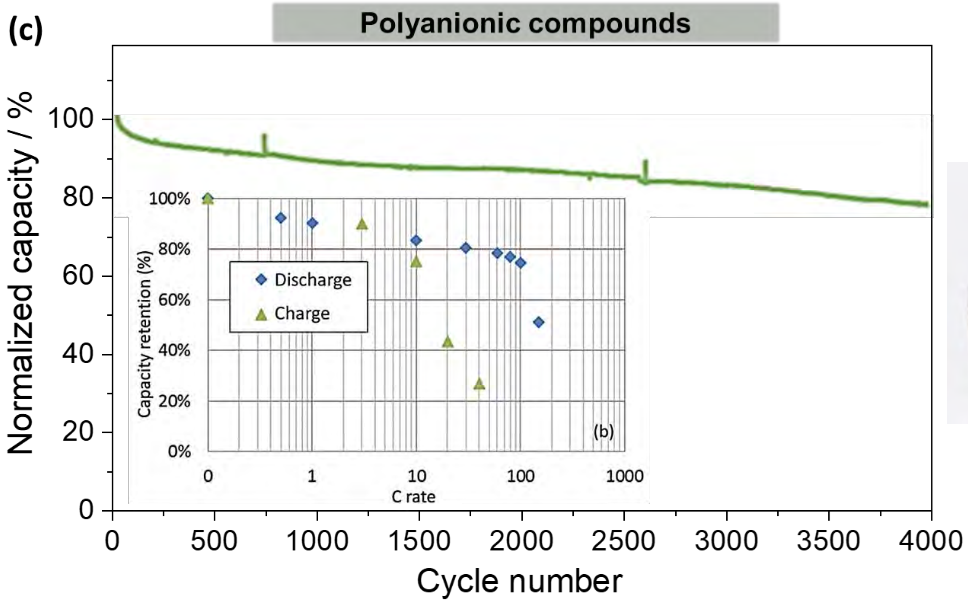






http://www.hinabattery.com/en/
https://www.faradion.co.uk/
Adv. Energy Mater. 2018, 8, 1702869

Toward commercial SIBs



Optimized hard carbon//$Na_3V_2(PO_4)_2F_3$
18650 full cell (75 Wh kg^{-1}) at 1C. 80% of initial capacity after 4000 cycles

http://www.tiamat-energy.com/

Advantages of NVP and NVPF:

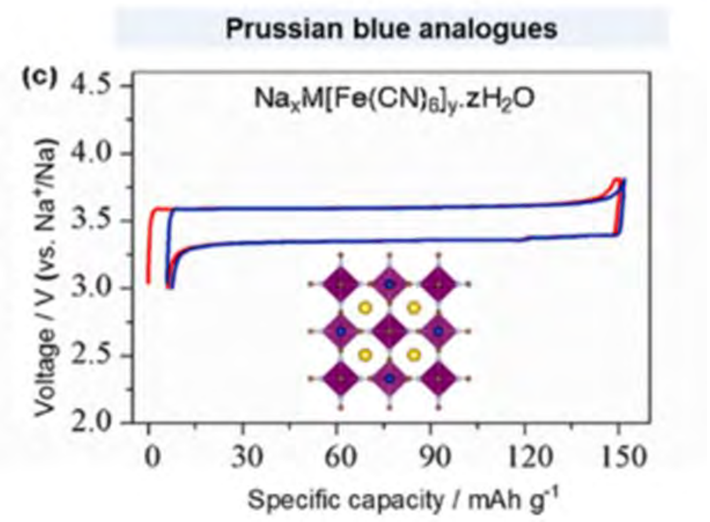
- Robust positive electrode materials for power-type NIBs, with energy densities of ca. 400 and 500 Wh. Kg^{-1}.
- Moisture stability when stored in air
- Thermal stability in the charged state of the battery

Disadvantages on NVP and NVPF:

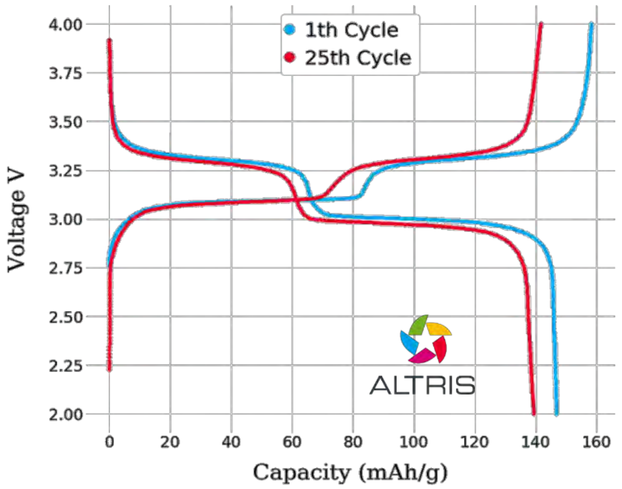
- Rather low gravimetric capacity
- Chemical composition: vanadium is a critical and highly toxic element (in its V^{5+} oxidation state). Its replacement by environmentally friendly elements (such as Fe, Mn) remains another challenge, as recent trials were demonstrated to be unsuccessful.

I. Hasa et al. Journal of Power Sources 482 (2021) 228872
https://news.cnrs.fr/articles/a-battery-revolution-in-motion

Positive electrode materials: Prussian blue analogues



https://www.altris.se/fennac/



PBAs are cyano-coordination compounds with general formula **AxM [M'(CN)6]1-y.zH2O** where

- **A** = alkali metal;
- **M, M'** = transition metal ion
- **y** = fraction of vacancies in the crystal structure

Three-dimensional framework with open channels for rapid alkali metal conduction. By careful tuning of the transition metal ion, the redox Potential changes and it is possible to use these compounds both as anodes and cathodes

https://natron.energy/

A maximum of ~2e- can be exchanged with PBAs using both M and M' as redox active metal ions.

Example: $Na_2FeFe(CN)_6$

2Na^+ insertion was reported for the stoichiometric composition

- capacity of ~170 mAh g^{-1}
- average cell voltage of ~2.7 V *vs* Na^+/Na

The presence of vacancies was found to limit the sodium ion storage capacity.

High power Na-ion cells:
CATHODE: mixed metal hexacyanoferrate
ANODE: manganese hexacyanomanganate

I. Hasa et al. Journal of Power Sources 482 (2021) 228872

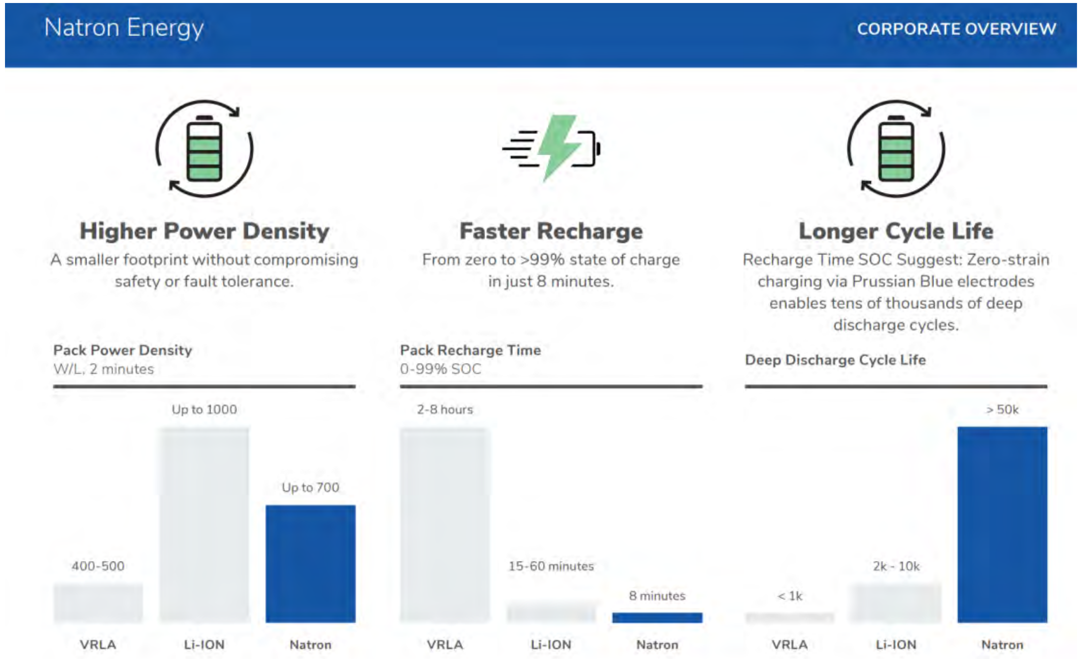
Toward commercial SIBs

SODIUM-ION AND SODIUM METAL BATTERIES

SANTA CLARA, CALIF. – MAY 4, 2022 – Natron Energy, Inc., a leading manufacturer of sodium-ion batteries, and Clarios International Inc., the global leader in low-voltage advanced battery technologies for mobility, today jointly announced a strategic agreement to manufacture the world's first mass-produced sodium-ion batteries.

The Clarios Meadowbrook facility will become the world's largest sodium-ion battery plant when mass production begins in 2023. This collaboration places the United States at the forefront of sodium-ion battery manufacturing.

Under this agreement, electrodes and large format cells based on Natron's proprietary Prussian blue electrode sodium-ion chemistry will be manufactured in an existing plant owned by Clarios in Holland, Michigan. The Clarios Meadowbrook plant was built as part of the ARRA program and has produced automotive lithium-ion cells for the past decade.

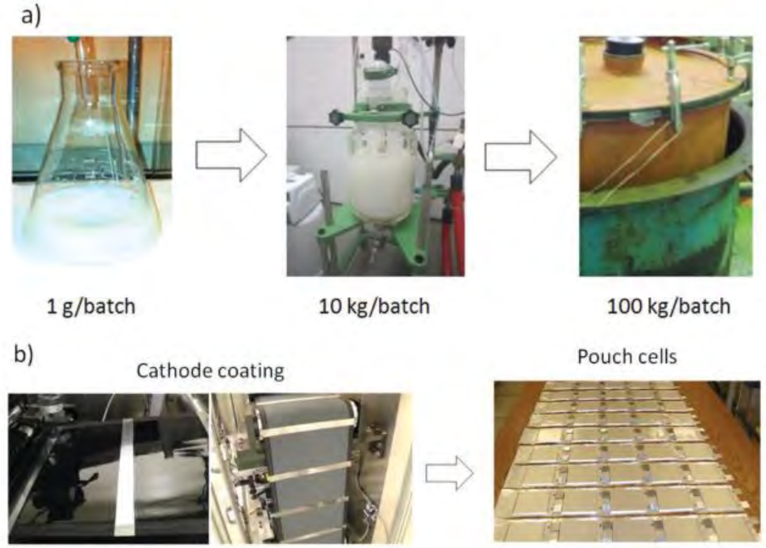


https://natron.energy/wpcontent/uploads/natron_collateral_clarios_press_release_050422.pdf

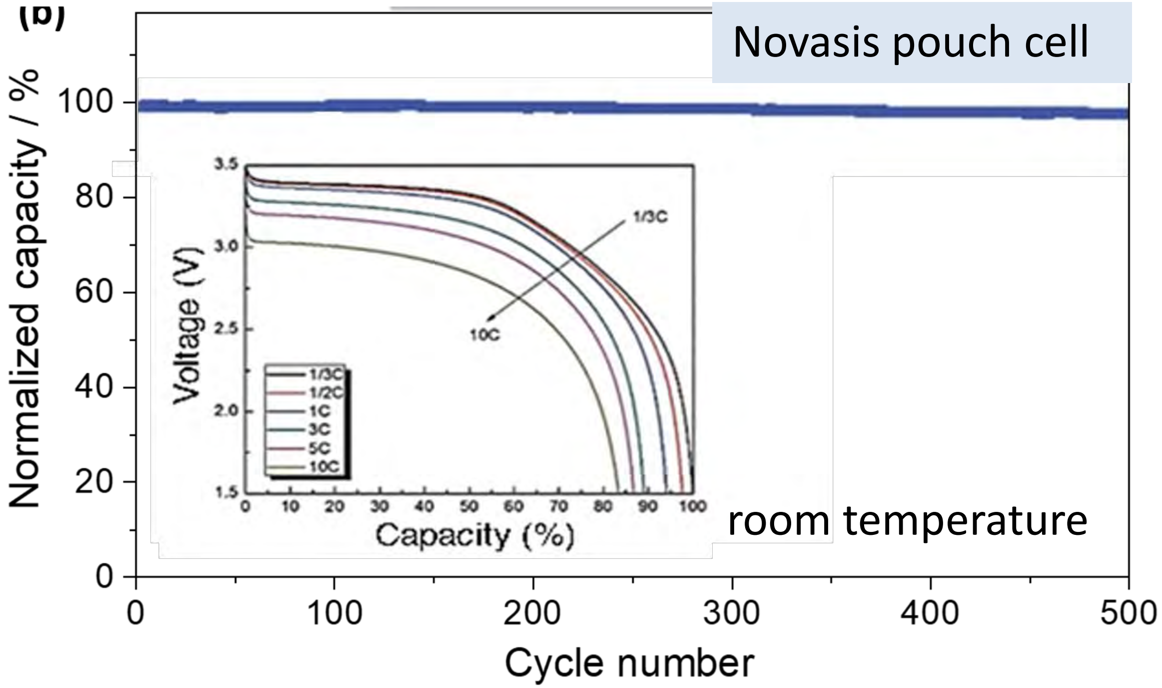
Toward commercial SIBs

Work performed at **Sharp Laboratories of America** Inc. and later at **Novasis** Energies Inc. generated a sodium cell employing a Prussian blue positive electrode and a HC negative electrode

Scale-up of Prussian blue analogue material synthesis from 1 g per batch to 100 kg per batch: precipitation reaction conducted at low temperature is used for their preparation without the need for high temperature calcination



pilot line scale with a roll-to-roll fabrication



~140 mAh g^{-1} at an average cell voltage of 3.4 V
specific energy of ~520 Wh Kg^{-1}, a value close to that of $LiFePO_4$ in LIBs

Adv. Energy Mater. 2018, 8, 1702869

SIMBA cell development

T4.1 Development of baseline cell

The baseline cell will constitute the baseline performance against which the solid state cell will be compared. Full cell of testing will be performed for the materials involved at coin cell level. The final pouch cell will be evaluated in terms of electrochemical performance and forensics.

Partners: **Altris, Elkem, KIT**

Role of Partners:

Altris: Supply of Prussian White cathode material;
Elkem: Supply of hard carbon anode material.
KIT: Electrochemical testing at coin cell level;
WMG: Processing of baseline pouch cell and associated testing and forensics.

Cathode: $Na_{2-x}Fe[Fe(CN)_6]_y.mH_2O$ Altris technology
Anode: Hard Carbon
Electrolyte: Liquid.

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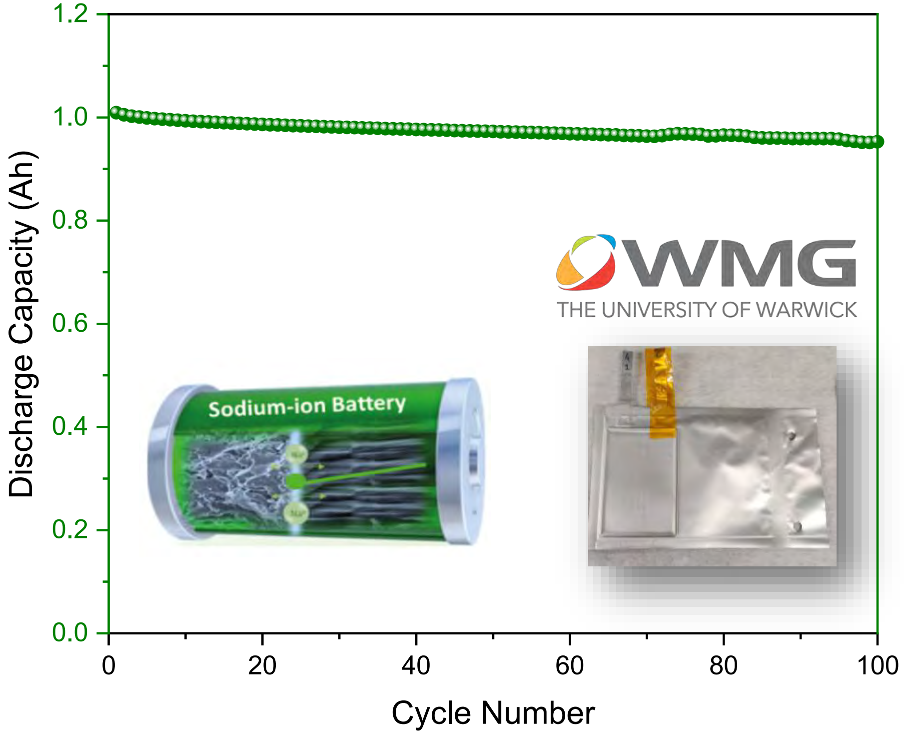
SODIUM-ION AND SODIUM METAL BATTERIES

SIMBA cell development

T4.1 Development of baseline cell   Task leader: WMG

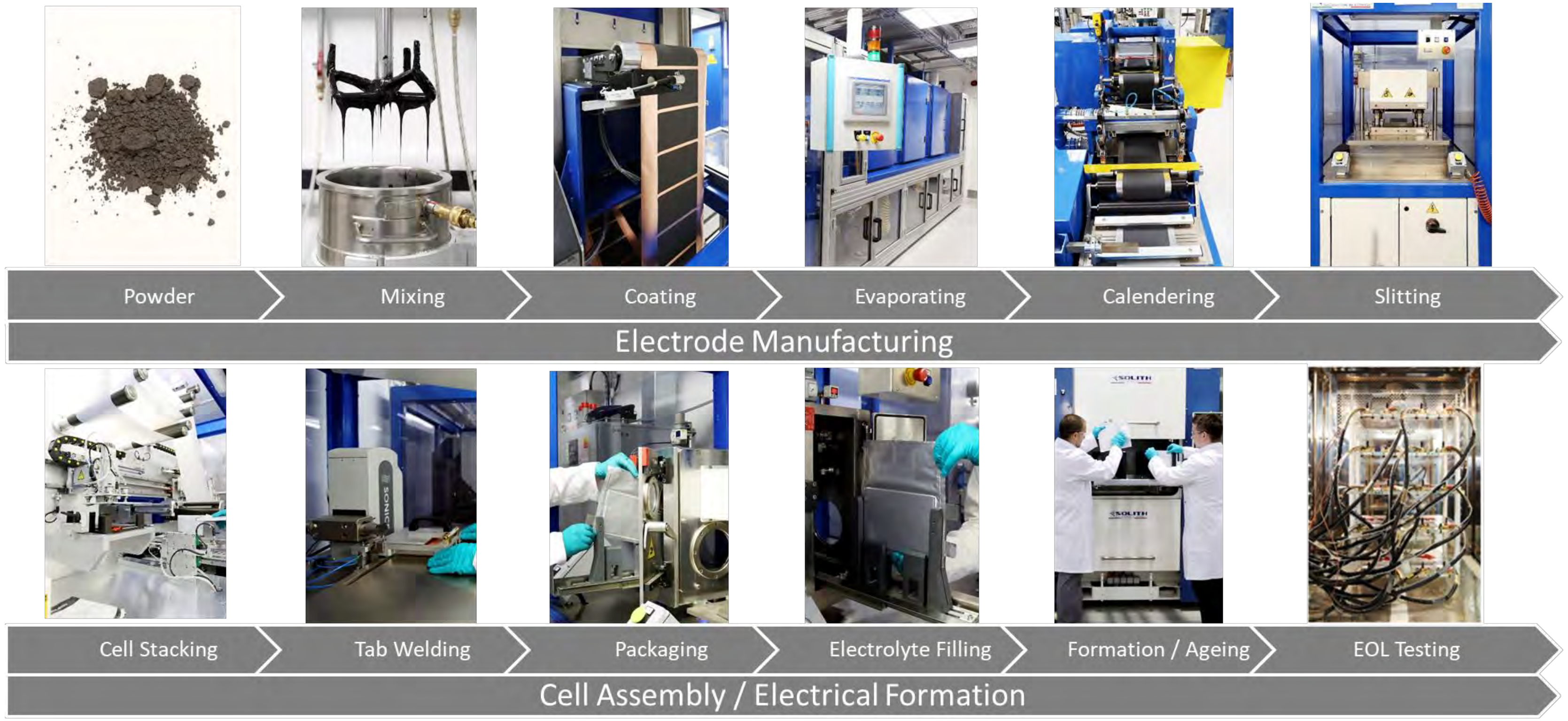
WMG
THE UNIVERSITY OF WARWICK



Cathode: $Na_{2-x}Fe[Fe(CN)_6]_y.mH_2O$ Altris technology.
Anode: Hard Carbon
Electrolyte: Liquid

1st objective and milestone of WP4 have been achieved. Great collaborative effort!

Sodium-ion cell manufacturing steps



Battery Scale Up facility at Energy innovation Centre (WMG)

SIBs are a drop in technology! Current manufacturing facilities can be employed!

Conclusions and remarks

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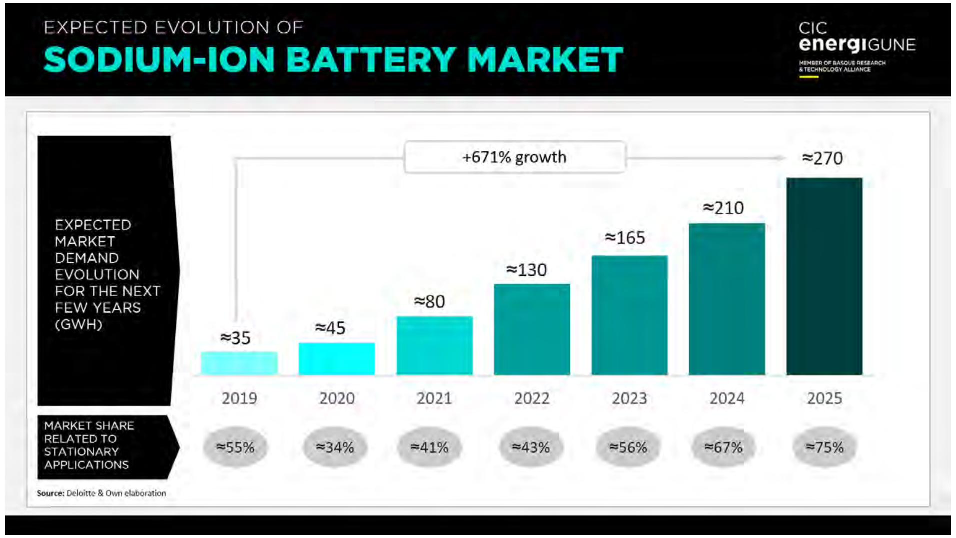
SODIUM-ION AND SODIUM METAL BATTERIES

- SIBs are a drop-in alternative for current LIB technology and applications and giga-factories designed to produce LIB's can be easily replaced with NIB's.
- SIBs may be fabricated using the same manufacturing methods and cell formats as LIBs.
- Improved sustainability. There is no requirement for resource limited elements such as Li, Co, Ni or Cu in either the cell chemistry or cell infrastructure.
- Aqueous processing of electrodes in line with SIB philosophy.
- Improved safety/abuse characteristics including safer storage and transportation (i.e., 0 V storage capability).
- Supply chains for most precursors and cell components are already established.
- Improved temperature range and performance.



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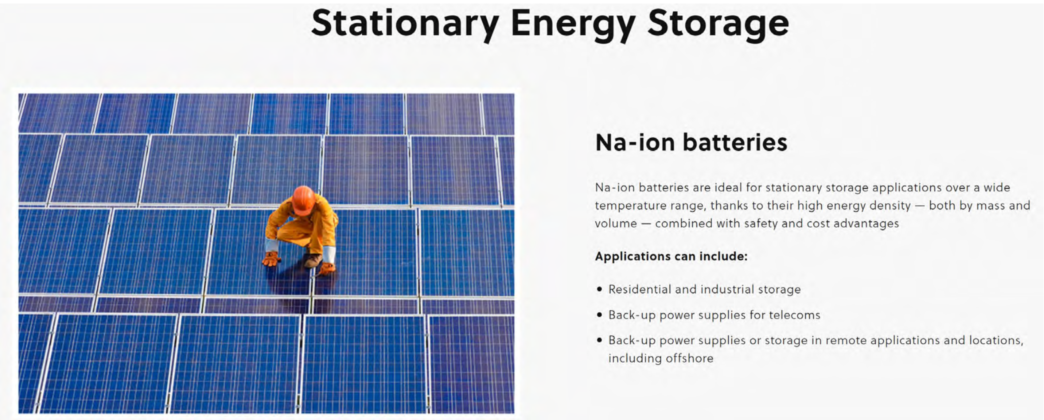

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